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Legacies of past forest management on present deadwood in montane mixed forests of Eastern Italian Alps

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Abstract

The role of deadwood on biodiversity conservation of forest ecosystems is widely recognised. Interest on deadwood has increased in the last years, and forest management policy regards deadwood as indicator of sustainable forest management.

This study took place in mixed montane forests in Eastern Italian Alps. The objective was to determine how past forest management, topography and forest structure influence deadwood accumulation. 124 sampling points were established in four Forest Reserves, where time of non-intervention ranges from 12 to more than 50 years. A multivariate analysis was performed to investigate the connections between forest stand characteristics and deadwood.

Coarse woody debris (CWD) volume in the reserves was similar to other recently-unmanaged forests in central Europe. Both stand characteristics and topographic factors determined CWD distribution. Basal area of living trees and human impact emerged as the most important factors. These aspects are connected with the input (density-dependent mortality) and the output (harvesting) of deadwood in the stand. In the next decades we expect an increase of deadwood, due to density-dependent mortality and disturbances. However, many decades in absence of human interventions are probably required to reach amount of deadwood similar to those in old-growth forests.

Keywords Alps; coarse woody debris; human impact; mixed forest; montane forest; multivariate analysis.

1. Introduction

Deadwood is an important component in the functioning of the forest ecosystem, as it plays an important role in biodiversity, trophic chains, forest natural regeneration, nutrient cycles and overall carbon storage (Harmon et al., 1986; Franklin et al., 1987; Jonsson and Kruys, 2001; Laiho and Prescott, 2004; Luyssaert et al., 2008). During the last decades research focused on the assessment of deadwood amount in forests have been common in North America (Spies and Franklin, 1988; McCarthy and Bailey, 1994; Sturtevant et al., 1997; Clark et al., 1998) and northern Europe (Sippola et al., 1998; Jonsson, 2000; Siitonen et al., 2000; Krankina et al., 2002). However, in central and southern Europe deadwood has received less attention (Bretz Guby and Dobbertin, 1996; Marage and Lemperiere, 2005; Motta et al., 2006; Lombardi et al., 2008).

In central and southern Europe human pressure has affected forest dynamics since prehistoric times (Farrel et al., 2000; Motta and Nola, 2001; Winter et al., 2010), peaking in the last century. In most regions of the Alps anthropogenic impact has been very severe because forests have been used for timber, fuel wood, forest litter, deadwood, branches and even small twigs collection and were subjected to grazing (Bürgi and Gimmi, 2007; Gimmi et al., 2008). During recent decades the anthropogenic impact on forests has considerably diminished, and in eastern Italian Alps a large part of forests have been withdrawn from regular management since the early 1950s (Martinis, 1990; Farrell et al., 2000; Lehringer et al., 2003). Moreover, the public attitude towards forests and forestry has dramatically changed. Past management was concentrated on what was being extracted from the forest, whereas current management emphasizes what is being left (Kohm and Franklin, 1997). In this context, quantity and quality of coarse woody debris (CWD) are regarded as important structural indicators of naturalness and biodiversity (Corona et al., 2003; MCPFE, 2003; Jönsson and Jonsson, 2007), providing information on the intensity of past human disturbances and closeness to old-growth condition (Stokland, 2001; Woodall and Nagel, 2006).

The amount of deadwood is determined by its inputs and outputs in the forest (Siitonen, 2001). Deadwood natural accumulation is influenced by disturbance regime, climate, tree species composition, tree size (von Oheimb et al., 2007), stand succession stage, stand structure (Siitonen et al., 2000), topography (Rubino and Mc Carty, 2003), decomposer organisms (Harmon, 2009). Besides, forest management can affect deadwood input. Silvicultural interventions alter tree species composition and forest structure, reducing competition intensity and mortality, and removing weakened trees having the highest potential to die (Siitonen et al., 2000 Rouvinen et al., 2002). Short rotation loggings interrupt natural stage development, preventing forest ageing and deadwood formation (Duvall and Grigal, 1999; Currie and Nadelhoffer, 2002; Vandekerkhove et al., 2009). Moreover, a direct removal of dead wood can occur to obtain fire wood and to reduce wildfire and pathogen attack risk (Wolynski, 2001). Therefore, deadwood quantities are normally lower in managed than in unmanaged forests (Gibb et al., 2005; Müller-Using and Bartsch, 2009; Vandekerkhove et al., 2009).

The present study was carried out in four Forest Reserves of the eastern Italian Alps located in the montane belt (1000-1600 m a.s.l.) where mature stands have been left unmanaged between 12 and 50 years. The vegetation type is a mixed forest of European beech (*Fagus sylvatica* L.), silver fir (*Abies alba* Mill.) and Norway spruce (*Picea abies* (L.) Karst.). Even if past anthropogenic impact has affected forest structure the native species are still present and regenerate naturally.

The aim of our analysis was to assess the legacies of past logging and stand characteristics on deadwood. Main research questions were: (1) what is the current volume of deadwood in mixed Fagus-Abies-Picea forests withdrawn from regular management in eastern Italian Alps? (2) What is the influence of former management, topography, and forest structure on quantity and quality of deadwood?

2. Methods

2.1. Study areas

The study took place in four Forest Reserves located in eastern Italian Alps (Val Novarza, Val Pontebbana and Col Piova in Friuli-Venezia Giulia Region, Ludrin in Trentino-Alto Adige Region, Fig. 1) with an elevation range from 1020 to 1630 m a.s.l. The predominant soil type is cambisol, developed on carbonatic substrate except for Val Pontebbana where a silicic substrate was dominant. Climate regime is similar among the reserves. Val Novarza and Val Pontebbana belong to “mesalpic district” with mean annual temperature averaging 8 °C, and annual precipitation averaging 1600 mm (Del Favero et al., 1998). Ludrin has a similar mean annual temperature, while annual precipitation differs from the other reserves averaging 1300 mm. Col Piova lies in the “esalpic district”, with mean annual temperature of 11 °C and precipitation of 1700 mm/year (Del Favero et al., 1998). In all the study sites the precipitation peaks are in spring (May - June) and autumn (November).

Stands are characterized by Norway spruce (*Picea abies* (L.) Karst.), silver fir (*Abies alba* Mill.) and European beech (*Fagus sylvatica* L.), representing the main species in Italian Alps montane forests. Other species (*Larix decidua* Mill., *Acer pseudoplatanus* L., *Sorbus aucuparia* L., and other montane broadleaf species) occur sporadically.

Val Novarza Forest Reserve (37 ha; latitude 46°27’ N; longitude 12°46’ E) is located at an altitude from 1300 to 1570 m a.s.l, and predominant aspect is west and north-west. Intensive selection cutting involving both beech and conifers occurred during 1940s, ending in 1953-1955 (forest management plan archive). No other activities were recorded in successive period, apart from a 37.5 m^3 cut in 1997 in the lower part of the reserve. Val Pontebbana Forest Reserve (37.6 ha; latitude 46°32’ N; longitude 13°10’ E) is east exposed, and altitude varies from 1240 to 1630 m a.s.l. The upper part was managed with group or individual selection cutting, and the last logging was conducted in the early 1960s (forest management plan archive). In the central part, last cutting was performed in 1982, while in the lower part intense selection cutting have been made until 1996. Col Piova Forest Reserve (36 ha; latitude 46°04’ N; longitude 12°26’ E) is predominantly west and north-west exposed, and altitude varies from 1020 to 1200 m a.s.l. At higher elevation, cutting brought to an end in 1960, while the rest of the forest was logged until 1989. Ludrin Forest Reserve (26.5 ha; latitude 46°07’ N; longitude 10°56’ E) occupies a part of a small valley north-south oriented, at an altitude from 1250 to 1350 m a.s.l. Several cutting occurred during 1950s, and the last silvicultural operations were performed in 1962. Comparison of ipsometric curves (tree diameter vs. tree height) of the three principal species showed a similar site productivity among the four reserves (data not shown). Slightly higher dominant height at Col Piova was probably related to lower elevation.

Fig.1.

2.2. Field methods

Sampling points were located on a 100x100 m regular grid superimposed on each reserve. 33 points were identified within Val Novarza, 33 in Val Pontebbana, 36 in Col Piova, and 22 in Ludrin Forest Reserve (Figure 1). Field data were collected between 2005 and 2007. In correspondence of each sampling point, three type of measurement were applied: (1) a circular sampling plot (12-m radius, at Val Novarza, Val Pontebbana, Col Piova,) or a squared plot (30-m side, at Ludrin) for live trees measurement, (2) two perpendicular rectangular plots (50 x 8 m) for the stumps and the snags, and (3) two perpendicular 50 m long transects for line intersect sampling (LIS) for the logs (Van Wagner, 1968).

Snags were defined as standing dead trees having diameter at breast height (dbh) > 7 cm and height > 1.3 m, and stumps were wood pieces with diameter at the top > 7 cm and height < 1.3 m. Logs were stems, pieces of stem or branches laying on the ground having at least 5 cm diameter and length > 1 m.

For all live trees and snags with dbh > 7 cm, dbh and height were measured. The number of stumps was recorded. The measurement of logs consisted of the diameter at each intersection point (LIS method). The decay stage of logs and snags was classified according to a class system from 1 (slightly decayed) to 5 (very decayed) (see Motta et al. 2006 for decay class description).

2.3. Stand and CWD descriptors

Several stand characteristics describing forest structure, human disturbance, and topography have been considered as possible factors (explanatory variables) influencing CWD quantity and quality (focus variables).

In each sampling plot, the following forest structure descriptors were calculated: tree density ($n \cdot ha^{-1}$), basal area (BA) ($m^2 \cdot ha^{-1}$), mean diameter at breast height (dbh) (cm), Shannon's diversity index for tree height (THD), proportion of trees having a BA bigger than the mean BA tree (%), BA proportions of the three principal species (%) (Drobyshev et al., 2008; Smirnova et al., 2008).

Human disturbance was evaluated through number of stumps ($n \cdot ha^{-1}$) (all stumps were considered anthropogenic) and the time elapsed since last intervention derived from forest management plan archives (years). Topography descriptors were percent slope (%) and elevation (m a.s.l.) derived from a digital elevation model (10-m resolution) using ArcGIS 8.2 (ESRI Inc.).

Deadwood constituted by snags and logs was referred as coarse woody debris (CWD). Stumps were not included in CWD, since they were considered as indicators of human impact (Rouvinen et al., 2002). The volume ($m^3 \cdot ha^{-1}$) of logs of each decay class and total was calculated using Van Wagner's formula (1968). The volume of standing dead trees (in classes and total) was estimated from yield tables, while the volume of the broken snags was estimated as a frustum of a cone (Motta et al., 2006). CWD was computed as logs and snags volume (CWD Tot), logs volume, snags volume, 1 and 2 CWD decay classes volume (CWD 1), 3, 4, and 5 CWD decay classes volume (CWD 2). To evaluate the occurrence of recently formed CWD in proportion to the total CWD volume, we calculated CWD ratio as the percent ratio between CWD 1 and CWD Tot.

2.4. Statistical analyses

Relationships between forest structure, human disturbance, topography and CWD were investigated adopting a multivariate approach. Redundancy analysis (RDA) was employed to explore relationships among all stand descriptors (explanatory variables) and CWD descriptors (focus variables) (Wimberly and Spies, 2001). Principal component analysis (PCA) was used to summarize CWD variability in few uncorrelated variables. Afterwards, a path analysis was employed to investigate the cause-and-effect relationships between CWD (expressed as PCs) and the most important explanatory variables (Shipley, 2000; Brais et al., 2005).

Prior to multivariate analyses, normality distribution of parameters was assessed and outlier analysis was performed using PcOrd 5 statistical package (McCune and Mefford, 1999). Each dataset was relativized by the standard deviate in order to put variables, that were measured in different units, on an equal footing (McCune and Grace, 2002).

All explanatory and focus variables calculated for each plot were included in the RDA matrix. This direct gradient analysis was performed using Canoco (Ter-Braak and Šmilauer, 1998) and the statistical significance of the relation between CWD and the explanatory variables was tested by a Monte Carlo test (9999 permutations).

A data matrix including six focus variables was processed to summarize CWD variability in fewer uncorrelated variables. PCA was performed using PcOrd 5 statistical package (McCune and Mefford, 1999) and statistical significance of the axes was tested by a Monte Carlo test (9999 permutations). Moreover, Pearson's correlation between explanatory variables and the principal components (PCs) was calculated to find out explanatory variables more related to CWD variability. Variables with Pearson's r over 0.15 (absolute value) were selected.

A path analysis, which is a specialized version of Structural Equation Models (Shipley, 2000), was employed to develop a model describing the influence of explanatory variables on quantity and quality of deadwood (expressed as PCs). A conceptual path model including variables selected by Pearson's correlation analysis was built under the underlying concept that different stand characteristics interact together to determine CWD in the reserves (Fig. 2). Afterwards, alternative models were tested considering a subset of variables to obtain a statistically significant model (Garbarino et al., 2009). Quantitative model comparisons used a combination of Akaike's Information Criterion (AIC) statistic and the Root Mean Square Error of Approximation (RMSEA). The latter is a goodness-of-fit index that is relatively independent of sample size. A model with RMSEA < 0.06 was considered a good fit (Hu and Bentler, 1999). All such models were tested and the models with the smallest AIC statistic were selected as the most parsimonious models (Hu and Bentler, 1999). Path analyses were conducted using Mx software that works with covariance matrices as input data and a maximum likelihood (ML) fit function (Neale, 1994).

Fig. 2.

3. Results

3.1. Amount of CWD in the reserves

Live tree volume was greatest at Val Novarza Reserve (594.9 m^3 ha^{-1}), while CWD volume was greatest at Ludrin (68.4 m^3 ha^{-1}). Col Piova showed the lowest values both for live and dead trees

(Table 1). However, values varied considerably among sample plots into the reserves, and the coefficient of variation ranged from 70% (Val Pontebbana) to 120% (Col Piova). A total absence of CWD was observed on one plot in Ludrin, and two plots in Col Piova. Based on outlier analysis, two plots involved in an uprooting episode in Val Novarza (CWD volume: 787 and 330 m^3 ha^{-1}) were excluded from analyses. Considering all reserves as a whole, volume contribution of snags and logs to CWD was similar (46.5 and 53.5% respectively), but snags prevailed (59.1%) at Ludrin and logs prevailed (75.0%) at Col Piova.

Table 1

Stand characteristics and CWD volume in the Forest Reserves.

3.2. Multivariate analyses of CWD and its anthropogenic and environmental relationships

RDA was used to relate deadwood data to anthropogenic and environmental data. Monte Carlo permutations (n = 9999) indicated relations between variables being statistically significant ($p = 0.01$). The first RDA axis explained 11.7 % of variance in CWD data, and the CWD-environment correlation for the first axis was 0.452. CWD Tot, CWD 1 and CWD 2 emerged to be correlated to each other, and were positively associated to stand density, elevation and basal area (Fig. 3). Volume of snags was highly related to density, while logs volume was related to slope. The number of stumps and management variables, both indicators of anthropogenic disturbance, were correlated to each other, and were negatively related to total volume of CWD, density, BA and elevation. Species BA proportions were not related to CWD variables. Beech proportion was higher at low elevation, and spruce at higher elevation. CWD ratio, a qualitative variable, seemed to be uncorrelated to other parameters.

PCA reduced CWD measures into uncorrelated components that explained most of the variation in the original dataset. The first two principal components explained 87.2% of the variation. PC 1 extracted 59.4% of the variation in the dataset, and was significantly associated with quantitative CWD variables, particularly with CWD Tot (Table 2). PC 2 extracted a lower percentage of variation (27.7%), and it was associated with the qualitative CWD variable, i.e. CWD ratio. Both axes were highly significant ($p = 0.0001$, Monte Carlo test). BA, density, THD, and elevation were negatively correlated with the first component (PC 1) (Table 3). Management, proportion of beech and number of stumps were negatively correlated to PC 1. Weak correlations ($r < 0.15$) with the second principal component (PC 2) were found.

Fig. 3.

Table 2

Principal component loadings for the first five axes for the four reserves.

Table 3

Pearson's correlation coefficients of the explanatory variables with the first 2 ordination axes (principal components).

3.3. Causal model for CWD

The conceptual model was used to derive alternative path diagrams for two synthetic descriptors of deadwood derived from the PCAs: CWD quantity (PC 1) and quality (PC 2). Seven explanatory variables on 12 were included in the first path model (Fig. 2). Since PC 2 explained a lower percentage of variation compared to PC 1, and no variables had r value over 0.15 with it, we did not perform a model to predict PC 2. A model emerged as having significant support (RMSEA < 0.001; AIC = -1.755) and included a topographic (elevation), a forest structure (basal area) and a human disturbance (management) variable (Fig. 4). CWD was positively influenced ($\beta = 0.22$) by basal area of live trees, but was negatively ($\beta = -0.20$) associated with management. The model included the interaction of topographic and anthropogenic influences in that the negative effect ($\beta = -0.58$) of elevation on human disturbance (management) was explicitly represented. Moreover elevation was positively ($\beta = 0.31$) associated with basal area.

Fig. 4.

4. Discussion

4.1. Disturbance regime and amount of CWD in the reserves

Connections between disturbance history and forest structure are critical for understanding ecological processes in the forest ecosystem (Bellemare et al., 2002; Foster et al., 2003; Gimmi et al., 2008; Fraver et al., 2009). The quantity and quality of deadwood can provide information on mortality processes and disturbance regime. Moreover, they can suggest the degree of forest naturalness, and indicate the proximity to the old-growth stage (Stokland, 2001; Woodall and Nagel, 2006; Winter et al., 2010).

In mixed temperate southern European forests, the natural disturbance regime mostly results in individual-tree death or small-scale disturbances caused by wind, insects, and fungi, while large-scale disturbances occur seldom (Nagel and Diaci, 2006; Firm et al., 2009; Kenderes et al., 2009). In the studied reserves, only 2 out of 124 plots had high amounts of deadwood, reflecting the absence of recent catastrophic disturbances. Distribution of deadwood in the reserves was related to single-tree mortality and small-scale wind disturbances.

In the eastern Italian Alps many forests have been left unmanaged in last decades due to social and economical changes. Their dynamics are presently influenced by autogenic and allogenic disturbances, but the current structure results from land use management history. Montane mixed forests analysed herein have been recently (from 12 to 50 years ago) withdrawn from regular management, thus an effect of former management on deadwood accumulation was expected.

The total CWD volume found in study reserves was comparable or slightly lower than other recently-unmanaged mixed forests in central Europe (Bretz Guby and Dobbertin, 1996; Vandekerkhove et al., 2009). However montane mixed Fagus-Abies-Picea old-growth forests have much more CWD, generally over 200 m^3 ha^{-1} (Vrška et al., 2001; Christensen et al., 2005; Motta et al., 2008). Our results suggest cessation of management for even 50 years is insufficient for accumulation of CWD comparable to old-growth forests.

4.2. Relationships between human disturbance, topography characteristics, forest structure and CWD components

Deadwood accumulation is influenced by a number of factors, resulting in a complex correlation structure between the involved variables. Thus, few studies have analyzed how different stand characteristics influence deadwood in a forest stand (Hély et al., 2000; Storaunet et al., 2000).

In the forests analysed herein, the number of stumps and time of non-intervention were strictly related to each other. In case of a lack of historical information, the number of anthropogenic stumps can be used as a proxy variable of human impact (Storaunet et al., 2005). The number of stumps indicates the intensity of cutting (Siitonen et al., 2000) while historical archives can precisely point out the time span of non-intervention.

Elevation was more important than slope percentage in shaping the forest structure and CWD characteristics. At higher elevation, spruce stands had a higher density of live and dead trees. Recently-disturbed stands located at lower elevations had lower BA and CWD volume and were dominated by beech trees.

Ordination analyses (RDA) indicated a relationship between forest structure and CWD, since BA and tree density were positively correlated with CWD quantity. This relationship probably reveals the effect of density-dependent mortality. Besides, past logging activities influenced actual forest structure, as BA was negatively related to management and stump density. A few studies have shown tree species composition influence deadwood characteristics (Brassard and Chen, 2008). Nevertheless, type or decay class distribution of CWD in the reserves was not strongly affected by species composition, although beech proportion was slightly negative related with CWD volume, possibly due to the rapid decomposition rate of its wood (von Oheimb et al., 2007). However, beech proportion was higher at low elevation, where generally smaller CWD amounts occurred, and a direct effect of beech proportion on CWD accumulation can not be ascertain.

Decay class distribution showed no pattern, as plots with higher quantity of low-decayed CWD had high quantity of high-decayed CWD as well. Moreover, the proportion of recently formed CWD (CWD ratio) was poorly correlated with other variables. Bretz Guby and Dobbertin (1996) found managed stands had more deadwood in higher decay stages than unmanaged stands in Switzerland. Burrascano et al. (2008) and Lombardi et al. (2008) found an opposite pattern in Central Italy. Inconsistency can be due to differences in species composition, disturbance type and decay processes (Yan et al., 2007). In contrast, the occurrence of logs and snags depended on plot characteristics. Snags were more abundant in stands having higher tree density, probably due to density-dependent mortality (Hély et al., 2000), while logs were more abundant in steep slope stands, where probability of uprooting is generally higher. Excluding anthropogenic stumps, effects of human disturbance on the type of CWD were not observed.

4.3. Effects of past forest management on forest structure and CWD accumulation

Clarify causal relationships that determine the accumulation of deadwood in forest ecosystems is critical for forest ecology and ecosystem management. Consistent with the majority of previous studies (e.g. Christensen et al., 2005), the path model indicated that CWD was related to the time elapsed from human intervention, and to the amount (basal area) of live trees.

The CWD accumulation reflects the cumulative balance between inputs through tree mortality and outputs through decomposition and harvesting (Harmon et al., 1986; Tinker and Knight, 2000). In the studied plots mortality was mainly due to competition or, less frequently, to individual uprooting. Since competitive mortality depends on tree density, the input of CWD was connected with the basal area of live trees.

Past management affected CWD input in the reserves. Logging activities reduced stand basal area, affecting density-dependent mortality. Moreover, suppressed, unhealthy and senescent trees with a high potential for death, representing potential sources of CWD, were generally removed. Besides, past management influenced directly the output, as CWD was generally removed during harvesting activities.

Consistent with the results of Christiansen et al. (2005) we found higher CWD quantities at higher elevation. This trend was probably related to the negative elevation effect on management intensity. Human impact on forest ecosystem is generally stronger at low elevation, due to proximity to human settlement, accessibility and higher forest productivity (Garbarino et al., 2009). Stands at higher elevation had higher basal area and lower human impact, and consequently higher CWD volume.

4.4. Future perspectives

The majority of studies on deadwood have been carried out on natural forests influenced by catastrophic disturbances (Harmon, 2009). However, in southern European montane forests, individual, small-scale or, more rarely, intermediate disturbances, are dominant processes driving forest dynamics (Leibundgut, 1987; Kenderes et al., 2009). Besides, past and present presence of man affects all southern European forests (Winter et al., 2010). In mixed montane forests analysed herein, past forest management and stand density seem to be the major aspects influencing CWD accumulation. In the absence of further human interventions, we believe that in the next few decades increasing density-dependent mortality and small disturbances will result a CWD accumulation. However many decades will be required for accumulations of CWD comparable to those in old-growth forests.

Quantifying deadwood dynamics is critical for modeling and managing forest ecosystems for the development of old-growth conditions in southern Europe. Future studies of interactions between environmental factors, human disturbance and deadwood are required, especially for those forests, which have been withdrawn from regular management for long periods (e.g. 50-100 years). Such forests will be increasingly common in the next several decades.

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Figure captions

Figure 1. Location of the 124 sample plots in the four Forest Reserves in eastern Italian Alps.

Figure 2. Conceptual model tested through path analysis. The model includes forest structure (Basal Area, Density, Beech proportion, THD, vertical diversity), topographic (Elevation), and anthropogenic (Management, Stumps) variables. CWD refers to the first principal component (PC 1) defined as deadwood quantity.

Figure 3. Redundancy analysis ordination biplot of 122 plots in the reserves. Dotted arrows represent the biplot scores of deadwood variables (CWD Tot = total CWD volume; Logs = logs volume; Snags = snags volume; CWD1 = volume of the 1st and 2nd CWD decay classes; CWD2 = volume of 3rd, 4th and 5th CWD decay classes; CWD ratio = CWD1 / CWD Tot). Full-line arrows represent the biplot scores of forest structure, human disturbance and topography variables (BA = basal area; Big Trees = BA proportion of trees larger than the mean BA tree; DBH = mean diameter at breast height; Density = number of live trees; THD = height diversity; Aa = fir basal area proportion; Fs = beech basal area proportion; Pa = spruce basal area proportion; Management = inverse of time of non-intervention; Stumps = number of stumps; Elevation = elevation a.s.l.; Slope = percentage slope).

Figure 4. Path diagram for the studied reserves. Continuous lines, positive paths; dotted lines, negative paths; single arrow lines, causal paths; double arrow lines, covariance paths. Thickness of causal path vectors corresponds to the strength of effect. Only significant path coefficients are presented next to each path.

Reserve	Area (ha)	Plots (n)	Elevation (m a.s.l.)	Last cutting (year)	Basal area (m^2ha^{-1})	Vol live trees (m^3ha^{-1})	Vol CWD (m^3ha^{-1})	Vol log (m^3ha^{-1})	Vol snag (m^3ha^{-1})
Val Novarza *	37.0	31	1300-1570	1953	53.1 (17.3)	594.9 (250.3)	45.8 (41.1)	25.1 (28.0)	20.7 (25.3)
Val Pontebbana	37.6	33	1240-1630	1996	43.6 (11.2)	470.7 (130.3)	31.0 (21.7)	16.4 (18.1)	14.6 (16.8)
Col Piova	36.0	36	1020-1200	1989	35.4 (11.3)	435.3 (158.1)	22.6 (27.0)	16.9 (22.5)	5.7 (12.4)
Ludrin	26.5	22	1250-1350	1962	48.3 (12.8)	531.3 (166.0)	68.4 (57.8)	28.0 (32.8)	40.4 (32.3)
All reserves	137.1	122	1020-1630	-	44.4 (14.8)	510.7 (187.6)	39.0 (40.0)	20.9 (25.2)	18.1 (24.5)

Table 1

Stand characteristics and CWD volume in the Forest Reserves.

Standard deviations are indicated in parentheses. Two plots were considered outliers and excluded from the Val Novarza dataset (*).

Axis	PC 1	PC 2	PC 3	PC 4	PC 5
% of variance	59.45	27.72	10.25	1.32	0.99
Logs	-0.43	0.08	**-0.72**	0.35	0.42
Snags	-0.43	-0.15	**0.68**	0.36	0.45
CWD Tot	**-0.52**	-0.02	0.00	0.20	**-0.70**
CWD 1	-0.35	**-0.56**	-0.10	**-0.70**	0.18
CWD 2	-0.48	0.31	0.08	-0.26	-0.21
CWD ratio	0.11	**-0.75**	-0.11	0.38	-0.24

Table 2

Principal component loadings for the first five axes for the four reserves.

Loadings greater than 0.5 (in absolute value) are indicated in bold.

	PC 1	PC 2
Density	**0.25**	0.06
Basal Area (BA)	**0.32**	0.08
Mean Diameter (DBH)	-0.08	0.01
Spruce (Pa)	0.09	0.03
Beech (Fs)	**-0.19**	-0.12
Fir (Aa)	0.10	0.05
Height diversity (THD)	**0.18**	0.09
Big trees	-0.07	0.03
Management	**-0.33**	-0.11
Stumps	**-0.18**	-0.01
Elevation	**0.22**	0.04
Slope	0.12	-0.03

Table 3

Pearson's correlation coefficients of the explanatory variables with the first 2 ordination axes (principal components).

Pearson's *r* values greater than 0.15 (in absolute value) are indicated in bold.

Figure1
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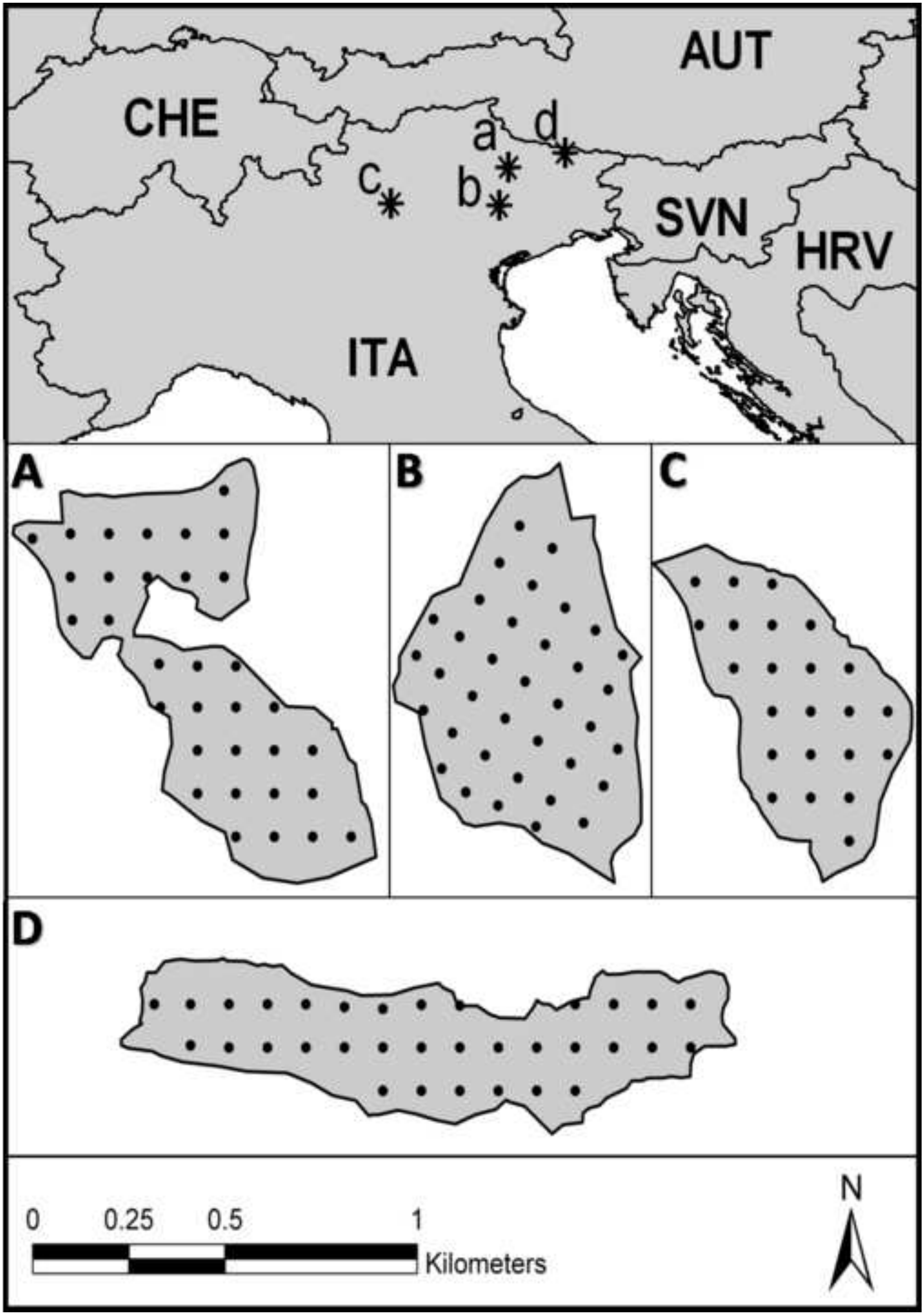
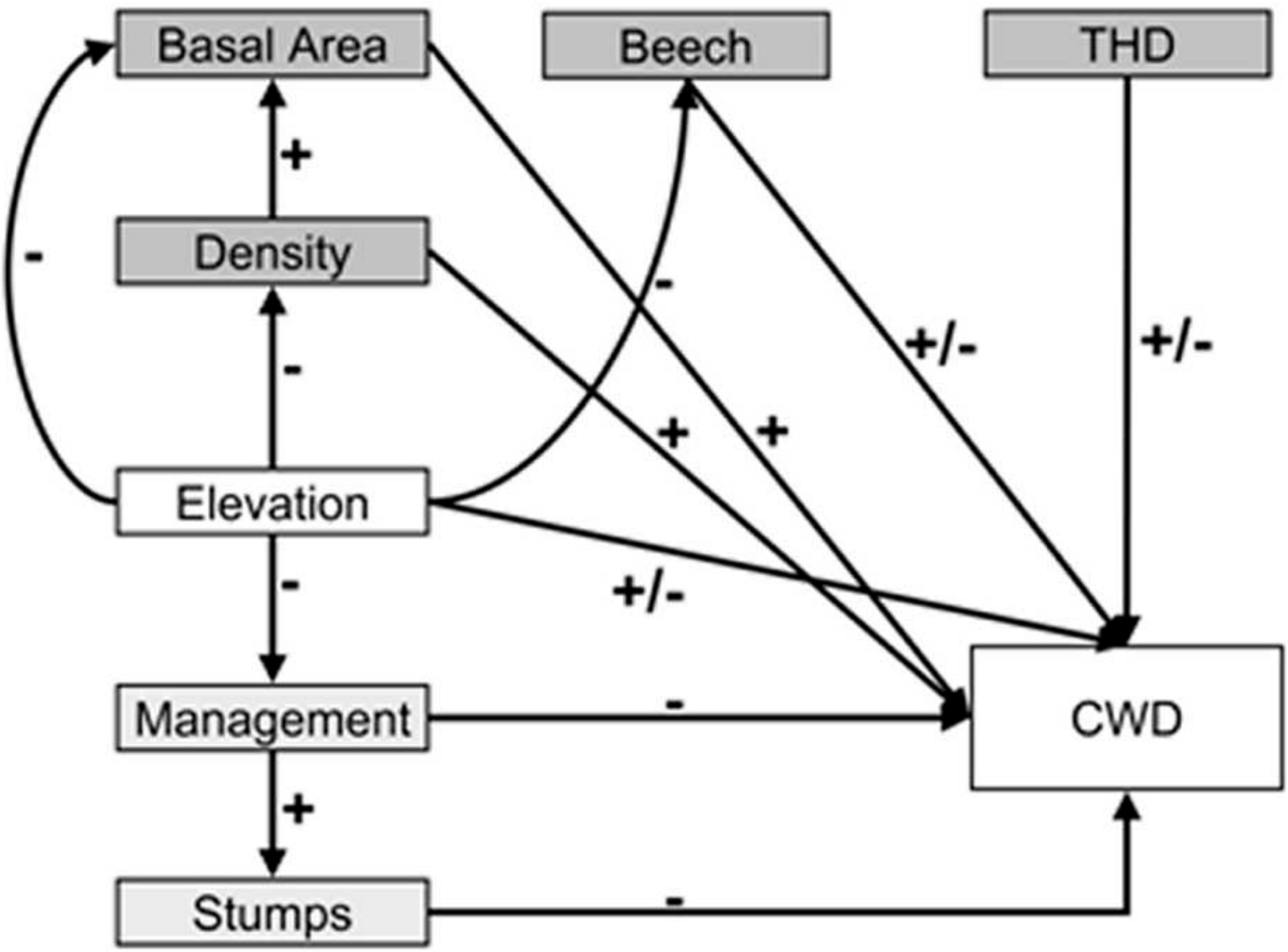
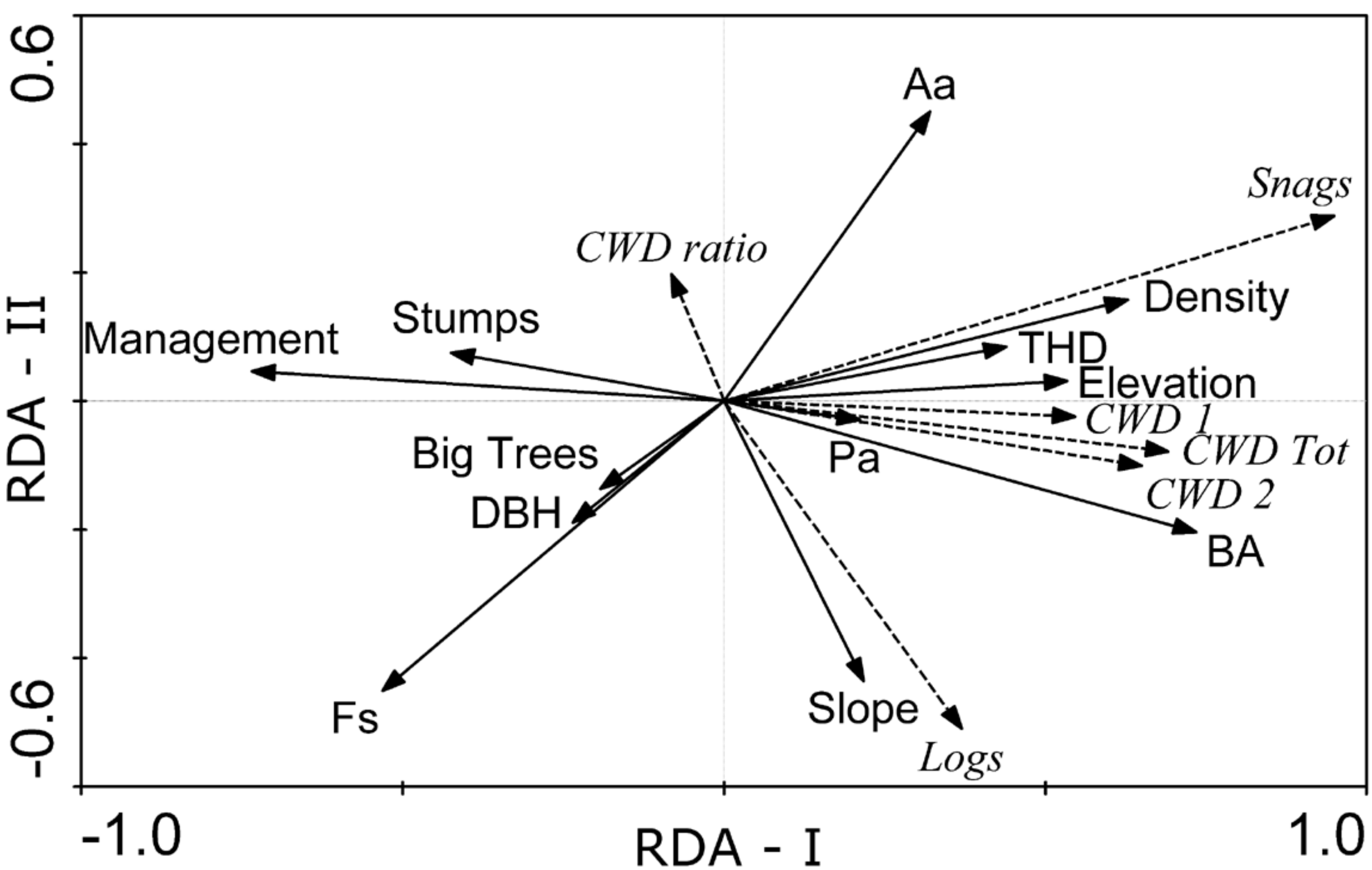


Figure2



Basal Area
Beech
THD
+
-
Density
-
+/-
+/-
-
+
+
Elevation
-
+/-
Management
-
CWD
+
Stumps
-

Figure3



Aa
Snags
CWD ratio
Density
Stumps
Management
THD
Elevation
CWD 1
CWD Tot
Pa
CWD 2
Big Trees
DBH
BA
Fs
Slope
Logs
0.6
-0.6
RDA - II
-1.0
1.0
RDA - I

Figure4